Interreg NEXT Black Sea Basin

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Establishing and Operating an Innovative Marine Technology Transfer Network for Enhancing the Transition to a Sustainable Blue Economy in the Black Sea Basin

Collection and Harmonization of Data, Images, and Videos from AUV

08/2026

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SECTION A – Data Collection

1.Utilization of AUV Technology in the Greek Pilot Site

At the current pilot site, an Autonomous Underwater Vehicle (AUV) was deployed on 14 November 2025 to support advanced underwater exploration and research activities. These vehicles represent a transformative step in data collection, enabling the acquisition of high-resolution images, video, and side scan sonar data of the seafloor and marine habitat structures. To facilitate collaboration and interoperability among partner organizations, standardized methods for data collection and storage are needed. Establishing standardized processes for collecting sonar data, imagery, and videos using the AUV, while emphasizing the value of harmonizing these datasets for regional scientific projects, will allow greater alignment with the Priority Blue and Smart Region objectives of the NEXT BSB Program.

The AUV selected for this activity is the NemoSens by RTsys, a lightweight, modular system equipped with multiple features like a propulsion unit and stabilizing fins for maneuverability; an embedded transducer and side scan sonar for high-resolution seabed mapping; and a mast containing key functionalities such as power control, GPS, WiFi, and UHF communication. It also includes a handle for easy deployment and the capacity to integrate external payloads, making it an ideal platform for pilot exploration.



***Figure 1**. Schematic representation of NemoSens AUV.*

In addition, the *NemoSens*® AUV is a fully modular system, and for this pilot activity, we will be equipped with all available configurations to maximize operational versatility. As shown in Figure 2, the AUV is delivered as a basic platform, allowing for custom integrations based on mission needs. For this mission, we will be equipped with both the CTD and SSS sensors, enabling simultaneous environmental monitoring and high-resolution seafloor imaging. The CTD sensor, an RBR Legato CTD, will profile conductivity, temperature, and depth, while the Side Scan Sonar (SSS) will provide detailed mapping of the seafloor. This combined setup allows the AUV to efficiently gather comprehensive data, enhancing its flexibility and scientific utility in marine research.



Figure 2. Payload options of NemoSens AUV by RTsys.

2. Deployment and Operational Overview of the NemoSens AUV

2.1. Preliminary deployment of the NemoSens AUV

A preliminary survey has been conducted to establish the strategy for planning and handling the Side Scan Sonar (SSS) data effectively. This initial phase focuses on understanding the specific requirements of the survey area, including seafloor characteristics, target detection, and optimal survey route planning. The aim is to develop a robust data-collection strategy that produces high-quality, high-resolution sonar images while minimizing data gaps. Additionally, considerations for data storage, processing, and analysis are being addressed, with an emphasis on establishing standardized procedures for handling the SSS data. By analyzing sample data and testing various sonar configurations, we aim to fine-tune our approach to maximize the efficiency and accuracy of the final dataset. This early planning phase also includes selecting appropriate software tools for data visualization, interpretation, and integration with other collected data, ensuring that all survey data can be harmonized and contribute effectively to the overall research goals.

The preliminary mission was conducted in the Nea Peramos Gulf, close to the city of Kavala, a site characterized by seagrass beds extending to a depth of 12 meters. The survey was carefully planned to use the Cousto software from RTsys, which enabled us to define mission parameters, navigation paths, and data-acquisition strategies.

During the mission, the AUV operated at 3 knots while maintaining an altitude of 3 meters above the seabed. Based on these parameters, a survey track was generated following a grid-line pattern with parallel lines spaced 12 meters apart, resulting in a 3-meter nadir line. This configuration ensured that each nadir line was captured by the subsequent line, maximizing coverage and data completeness.

In addition, the GoPro camera mounted on the AUV was meticulously configured to record video at ultra-high 4K resolution and 60 frames per second. This configuration was carefully selected to capture extremely detailed, high-fidelity visual information about the seafloor, seagrass beds, and associated marine habitats. The high temporal and spatial resolution of the footage

allows for precise observation of habitat structures, fine-scale features, and subtle environmental variations. Furthermore, this high-quality dataset is specifically intended to support the development and training of machine learning models, enabling automated recognition, classification, and analysis of benthic habitats and underwater objects. By providing a robust, comprehensive visual dataset, these recordings enable advanced AI-driven analyses that significantly enhance the accuracy, efficiency, and scalability of marine ecological monitoring and research.

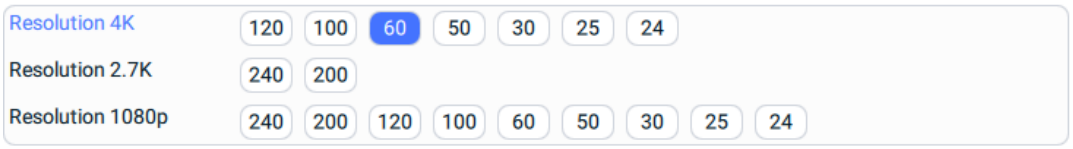


***Figure 3**. GoPro camera configuration*

This preliminary deployment enabled us to133 assess vehicle performance, manoeuvrability, and sensor functionality under real-world conditions. The planned mission layout is illustrated in the image below, providing a visual overview of the intended survey track and data collection points.

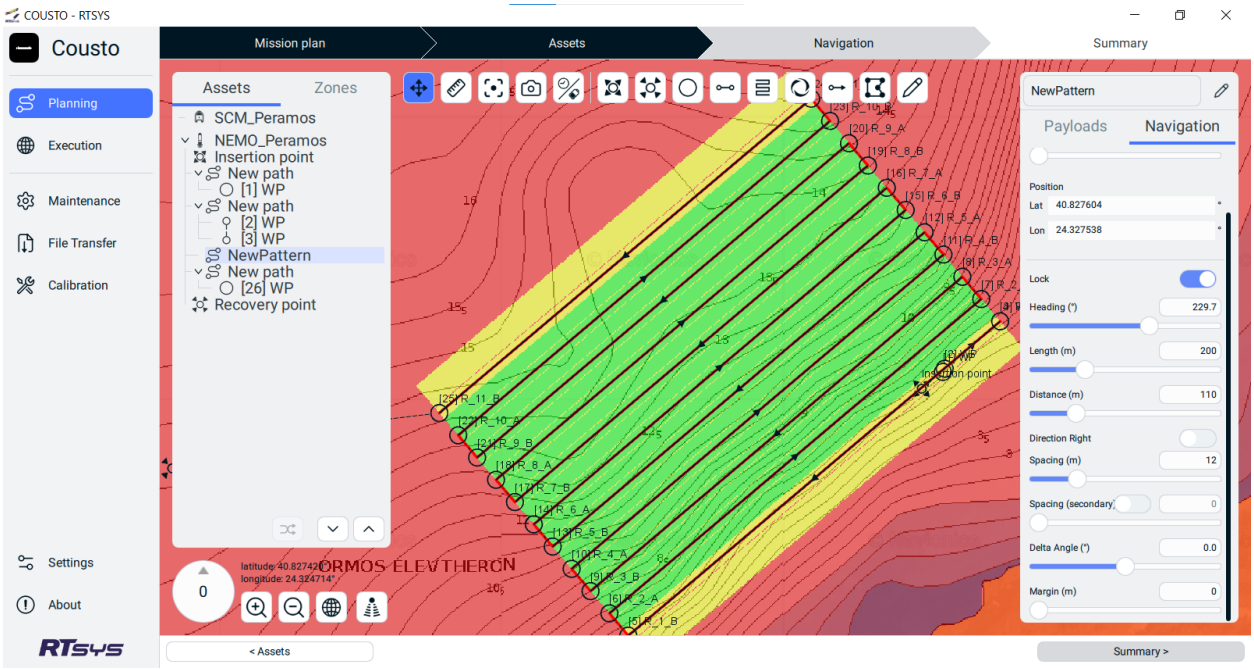


***Figure 4**. Preliminary AUV mission plan for the Nea Peramos Gulf area.*

The preliminary mission in the Nea Peramos Gulf was carefully monitored and controlled to ensure safe and effective operation of the NemoSens AUV. The AUV maintained real-time connectivity with the surface station through the SCM system, which transmits and receives messages while providing continuous updates on the tactical situation of all deployed assets. The SCM facilitates communication not only with the surface station but also with other underwater vehicles, and in the absence of positioning buoys, it serves as a crucial repositioning tool for the AUV.

Additionally, the GEOsys system was used to maintain UHF communication with the AUV over distances up to 5 km, enabling operators to monitor heading and distance relative to the remote control. This dual connectivity setup ensured reliable command and control throughout the mission, provided accurate situational awareness, and supported the safe execution of survey tasks. The mission was conducted from a boat that traveled from the coast to the survey area and back, with a total duration of approximately 2 hours. The mission duration, operational path, and data acquisition points are illustrated in the image below, providing a visual overview of the mission in progress.

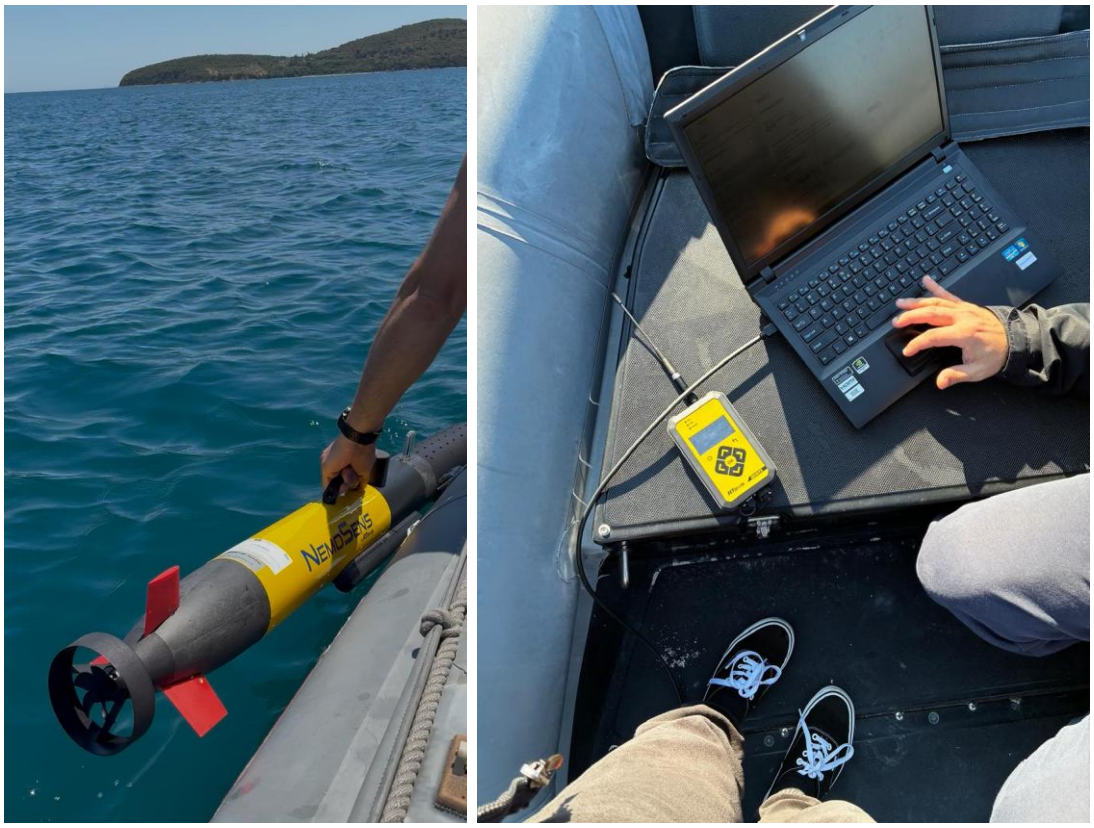


***Figure 5**. Snapshots from the conducted preliminary mission.*

2.2. Survey overview

During the 6th reporting period, six additional field missions were conducted using the NEMOSENS Autonomous Underwater Vehicle (AUV) in the coastal waters near Vrasida Bay and Ammolofoi Beach, bringing the total to ten field missions, following the four conducted during the 5th reporting period. The surveys focused on examining the seabed and assessing the extent of areas with sonar indications that may be associated with seagrass meadows. The missions generated georeferenced side-scan sonar records and navigation tracks that provide spatially referenced evidence of the seabed conditions encountered along the surveyed transects.

The figures below summarise the surveys and individual tracks executed during the missions, including those that did not complete successfully, as well as the depth and range test tracks.



***Figure 6**. Overview of the surveys conducted.*

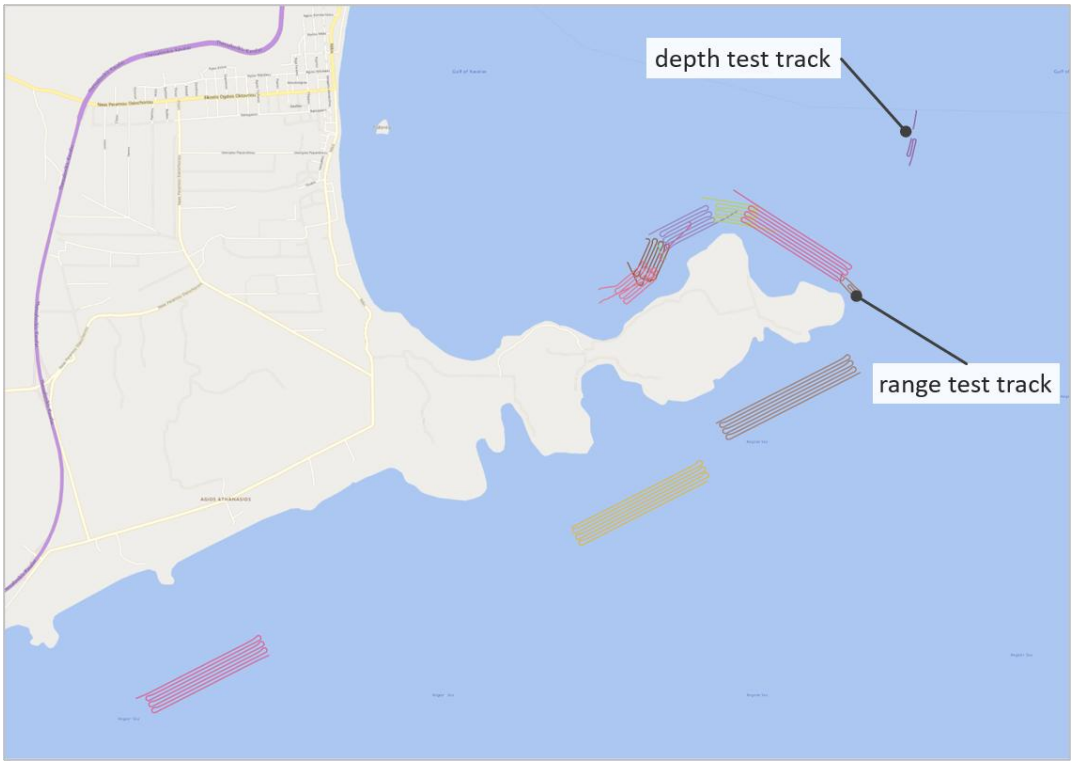


***Figure 7**. Overview of the survey tracks, including the depth and range test tracks.*

2.3. Survey approach

The AUV followed predefined survey tracks, with its side-scan sonar recording acoustic backscatter from both sides of the vehicle. This sonar imagery was reviewed alongside the corresponding mission map and geographic coordinates, and cross-checked against video footage collected during the same surveys to provide ground-truth confirmation of the acoustic signatures. This combined approach allowed us to relate observed acoustic patterns and seabed features, as validated visually through the video data, to their position within each survey area.

The assessment relied on visual interpretation of both the sonar records and the accompanying video footage. Attention was given to continuous or patchy acoustic textures that could indicate submerged vegetation, with video imagery used to confirm or clarify these interpretations where available. Variations in backscatter, seabed texture, and localized objects or irregular features were also noted as part of the general characterization of the surveyed seabed, drawing on both data sources to support a more reliable assessment.

For the survey missions (Missions 7 to 10), the AUV followed a grid pattern of seven parallel lines spaced 20 meters apart, covering a strip approximately 120 meters wide and 650 to 820 meters long (depending on the mission). To allow the AUV to execute a proper turn before beginning the next line, a margin of 18 meters was added at the start of each line. The AUV operated at a speed of 3 knots and maintained a constant altitude of 5 meters above the seabed along each survey line, while transits to and from the survey lines were performed at a fixed depth of 3 meters below the surface. The side-scan sonar was configured with a range of 25 meters per side and 1,024 samples per ping, so that the swaths of adjacent lines overlapped and the nadir gap of each line was covered by the neighbouring lines. Each mission continues the previous one, extending the existing coverage into a single, coherent survey of the area. Figure 8 below shows the routes of the survey missions conducted during this period.

In addition to the survey missions, two short test missions were carried out to evaluate specific operational parameters of the AUV (Figure 9). The range test consisted of four parallel lines, approximately 80 meters long and spaced about 15 meters apart, and was used to assess the performance of the side-scan sonar with a 20-meter range setting while maintaining an altitude of 5 meters above the seabed. The depth test consisted of three parallel lines, approximately 105 meters long and spaced about 15 meters apart, and was conducted in deeper water of approximately 32 meters to verify that the AUV could maintain its target altitude of 5 meters above the seabed at greater depths, and to assess whether the available natural light at this depth was sufficient for the GoPro camera to capture usable footage of the seabed. The AUV first descended to an initial waypoint at 18 meters depth, and the side-scan sonar range was also set to 20 meters. Both test missions were performed at a reduced speed of 2 knots, providing operational insight for planning future surveys in deeper areas and for selecting appropriate sonar range settings.

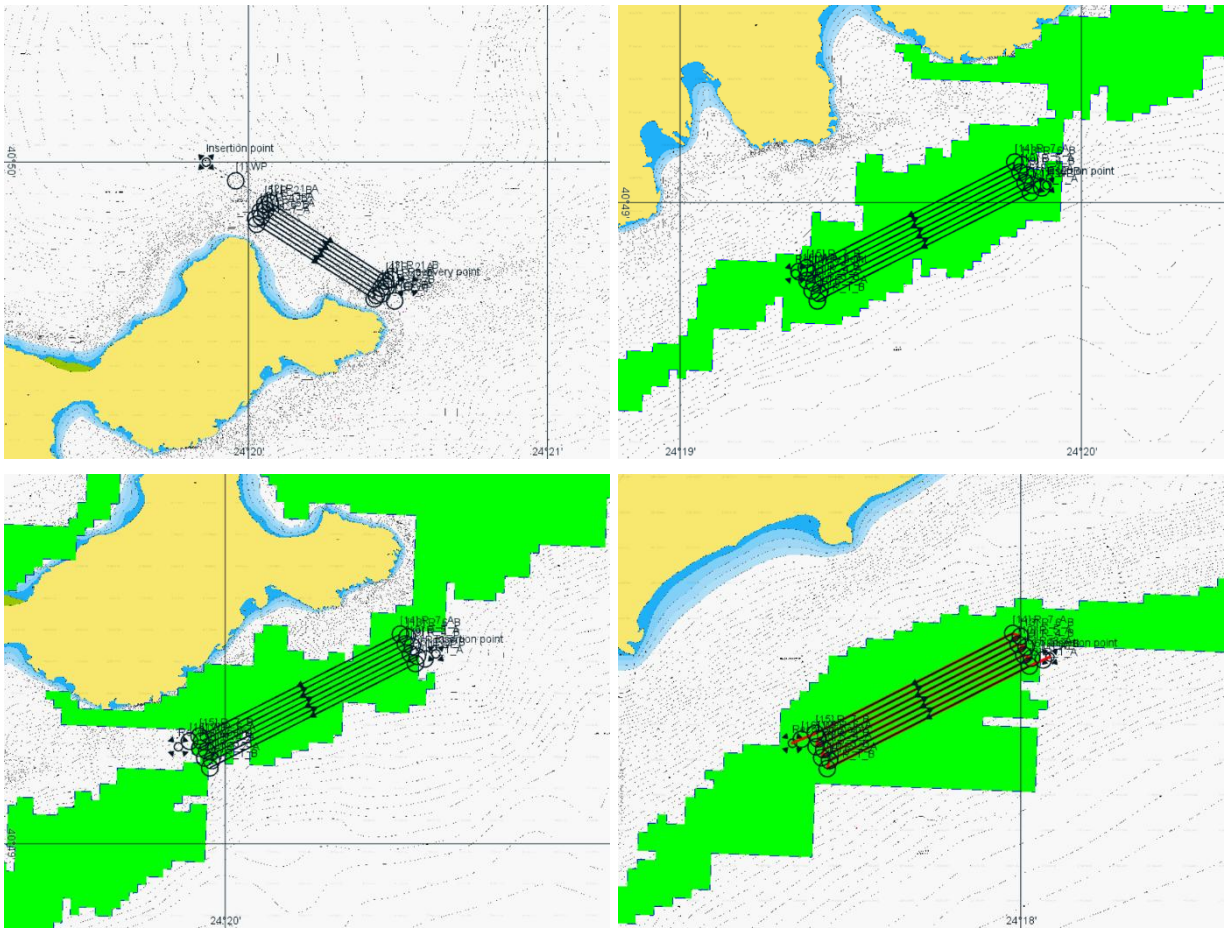


***Figure 8**. Planned AUV missions in the Peramos Gulf and Vrasidas bay area.*

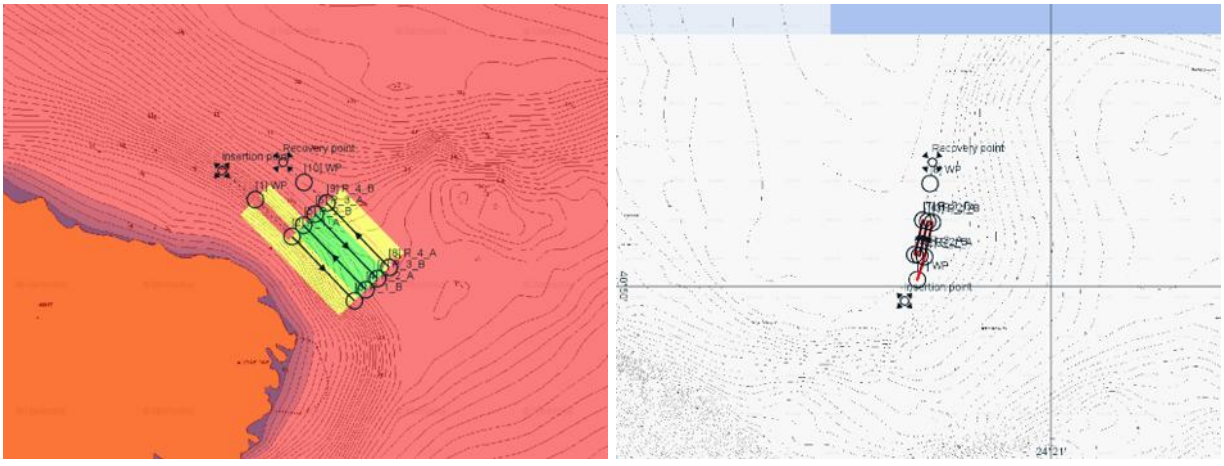


***Figure 9**. AUV test missions in the Peramos Gulf: range test (20 m sonar range) and depth test (approximately 32 m water depth).*

2.4. Main results

Along portions of the AUV tracks covered during the five missions in the coastal area near Vrasida bay and Ammolofoi beach, the side-scan sonar records revealed indications consistent

with patches of Posidonia oceanica, although the observed coverage was relatively sparse. No seagrass was detected during the depth test conducted at approximately 32 meters. Overall, the records showed localized areas of continuous or patchy acoustic texture, interspersed with broader zones of bare seabed and spatial variation in acoustic backscatter. This result is limited to the areas and transects surveyed during the reporting period and should not be interpreted as a complete characterization of seagrass distribution across the wider coastal zone.

The figure below shows a section of the side-scan sonar waterfall display where seagrass is visible, alongside a corresponding video comparison on the right for ground-truth verification.

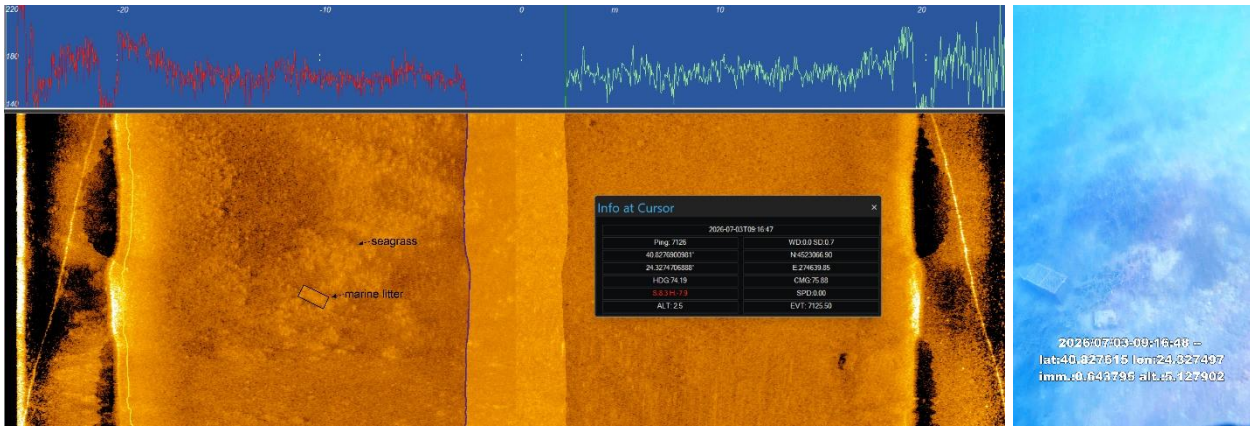


***Figure 10**. Section of the side-scan sonar waterfall display showing acoustic signatures of seagrass patches (left), alongside corresponding video footage used for ground-truth comparison (right).*

Following data retrieval, the raw side-scan sonar records were processed in SonarWiz software (https://chesapeaketech.com/) to improve the quality and interpretability of the acoustic imagery.

This included correcting heading variations, applying pitch corrections to ensure accurate spatial positioning of the sonar returns, and applying an Empirical Gain Normalization (EGN) method to balance the acoustic backscatter intensity across the swath and compensate for range-dependent signal attenuation. A Destripe filter (50 pings) was also applied to remove striping artefacts and improve the overall consistency of the acoustic returns across the waterfall. The water column and nadir line were first removed to eliminate the central portion of the swath where no meaningful seabed information is present, followed by trimming the far-range limit to exclude the outer edge of the swath, where signal quality degrades and returns become less reliable.

Once cleaned, the individual sonar lines were geocoded and mosaicked using the Root Mean Square (RMS) method (the RMS of the stacked pixels is displayed) to produce a continuous, georeferenced representation of the surveyed seabed.

The resulting mosaic, shown in Figure 11 below, illustrates the spatial distribution of acoustic backscatter across the survey area, allowing the identified seagrass patches to be visualised in their correct geographic position alongside the surrounding seabed features. Figure 12 then places the mosaics of all survey areas on the base map of the Nea Peramos coastal area, providing an overview of the full extent of the seabed coverage achieved, from the Vrasida bay

area to the survey strips south of the peninsula towards Ammolofoi beach, together with the locations of the depth and range test missions.



***Figure 11**. Detail of the georeferenced side-scan sonar mosaic from the Vrasida bay survey area, showing the spatial distribution of acoustic backscatter.*



***Figure 12**. Georeferenced side-scan sonar mosaics of all survey areas overlaid on the base map of the Nea Peramos coastal area, including the depth and range test missions.*

2.4.1. Lessons Learned

Several observations were made during this period that will inform the planning and analysis of future missions. Regarding the platform, the capacity of the AUV battery proved too small to

cover larger survey areas in a single mission.

Regarding the side-scan sonar, the operating altitude should be reconsidered in order to obtain clearer SSS imagery. In addition, the segments during which the AUV ascends or descends to reach the requested altitude should be removed from the analysis. The StarFish SSS also records water-column data, and it has not yet been decided whether this information should be removed during processing. A possible cause is the StarFish 454's wide 60° vertical beam, which is tilted 30° downward.

Regarding the camera, an altitude of 3 meters was found to be optimal for capturing seagrass. Surveys should also be carried out in calm sea conditions, as waves cause light reflections and increase water turbidity, reducing the quality of the footage.

3.Deployment and Operation of the Seaber AUV in Bulgaria

3.1. Survey overview

During the 5th reporting period, two field missions were conducted using an Autonomous Underwater Vehicle (AUV) in the coastal waters near Balchik and Fichoza, Bulgaria. The surveys focused on examining the seabed and assessing the extent of areas with sonar indications potentially associated with seagrass meadows. The missions generated georeferenced side-scan sonar records and navigation tracks that provide spatially referenced evidence of the seabed conditions encountered along the surveyed transects.

3.2. Survey approach

The AUV followed predefined survey tracks while its side-scan sonar recorded acoustic backscatter from both sides of the vehicle. The sonar imagery was reviewed together with the corresponding mission map and geographic coordinates. This combined approach enabled the survey team to relate the observed acoustic patterns and seabed features to their position within each survey area.

The assessment was based on visual interpretation of the available sonar records. Attention was given to continuous or patchy acoustic textures that could potentially indicate submerged vegetation. Variations in backscatter, seabed texture, and localized objects or irregular features were also recorded as part of the general characterization of the surveyed seabed.

3.3. Main results

No sonar indications interpreted as seagrass meadows were identified along the AUV tracks covered during the two missions. The available records instead showed spatial variation in acoustic backscatter and localized seabed features. The result is limited to the areas and transects surveyed during the reporting period and should not be interpreted as evidence of the complete absence of seagrass from the wider coastal zones of Balchik or Fichoza.

The two missions demonstrate the practical use of autonomous underwater surveying for rapid, georeferenced seabed screening. The collected dataset can support the planning of future targeted surveys and the selection of areas requiring additional investigation or verification with complementary methods.

3.4. Balchik survey

The Balchik mission included georeferenced AUV transects with simultaneous visualization of the vehicle track and side-scan sonar record. The integrated display confirms the mission's spatial coverage and allows individual acoustic observations to be linked to precise coordinates.

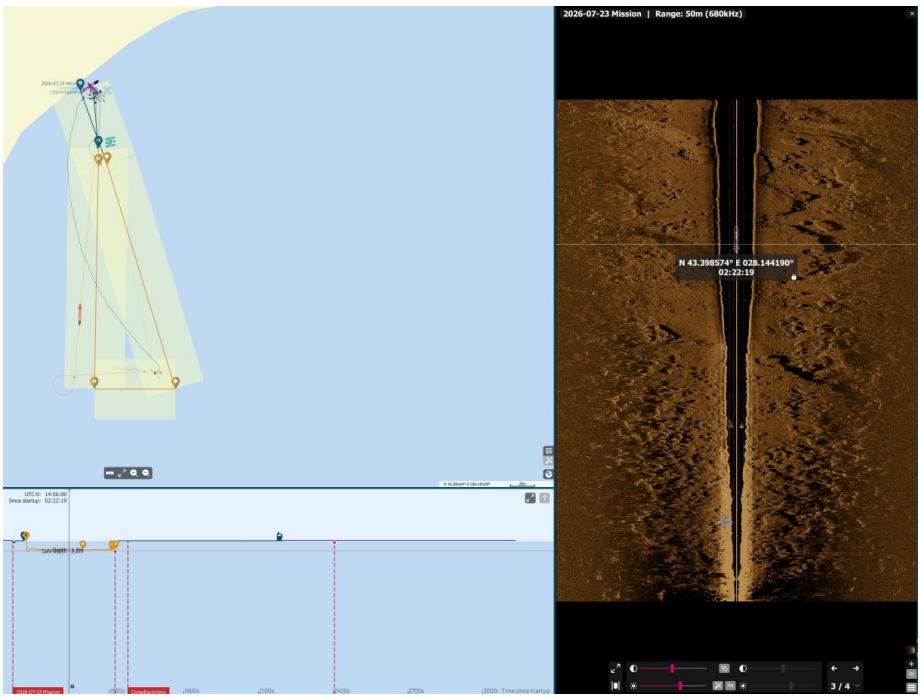


Figure 13. Integrated mission map and side-scan sonar visualization from the AUV survey near Balchik on 23 July 2026.

3.5. Fichoza survey

The Fichoza mission produced additional side-scan sonar coverage of the coastal seabed. The records illustrate relatively continuous acoustic textures along parts of the transects, along with changes in backscatter intensity. Within the survey tracks reviewed, no patterns were interpreted as seagrass meadows.

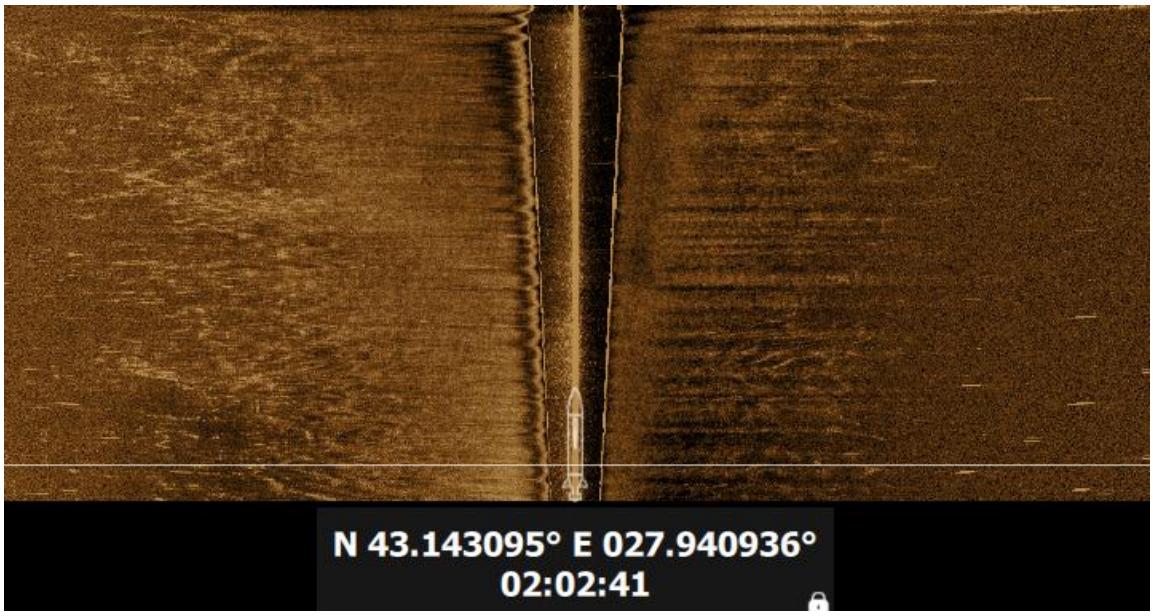


***Figure 14**. Representative side-scan sonar image from the AUV survey near Fichoza (approximately 43.143095° N, 27.940936° E).*

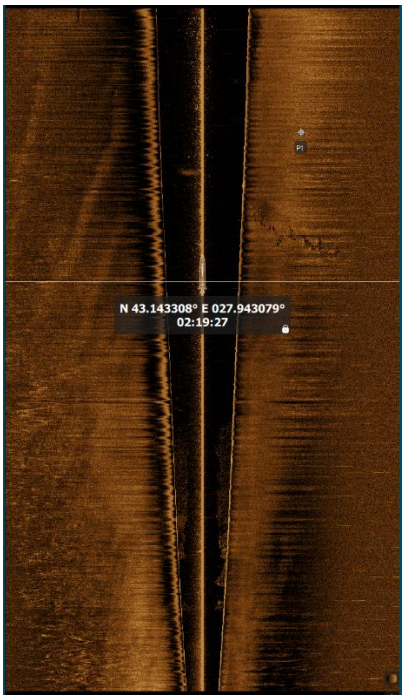


***Figure 15**. Extended side-scan sonar transect from the Fichoza survey (approximately 43.143308° N, 27.943079° E).*

3.6. Summary of completed missions

Mission	Survey area	Platform	Main observation
1	Balchik	AUV with side-scan sonar	No sonar indications interpreted as seagrass meadows along the surveyed tracks.
2	Fichoza	AUV with side-scan sonar	No sonar indications interpreted as seagrass meadows along the surveyed tracks.

3.7. Conclusions

Two AUV missions were successfully completed between 25 April and 23 July 2026 in the coastal waters near Balchik and Fichoza. The missions provided georeferenced side-scan sonar imagery and navigation information suitable for screening the seabed for potential seagrass habitats.

Review of the available sonar imagery did not identify acoustic patterns interpreted as seagrass meadows within the covered survey tracks. This finding documents the conditions encountered during the two missions but remains spatially limited to the surveyed transects.

Future work may include additional AUV coverage, repeated surveys under comparable conditions, and targeted visual or sampling-based verification in areas of potential interest. Combining side-scan sonar observations with complementary field evidence would strengthen habitat interpretation and support the development of a more comprehensive picture of seabed conditions.

3.8. Contribution to project objectives

The completed activities contribute to the project objectives by demonstrating the application of autonomous underwater technologies for coastal habitat screening and by generating georeferenced survey material that can be compared with observations from other pilot areas. The collected records also provide a basis for harmonizing seabed survey approaches and planning subsequent monitoring activities.

4.Deployment and Operation of the NemoSens AUV in Romania

4.1. Executive summary

This report consolidates the Romanian pilot contribution to EfxINNOs, focusing on the acquisition and harmonisation of autonomous and remotely operated underwater vehicle (AUV/ROV) data, preliminary optical data processing, and a methodological framework for future benthic habitat mapping. NIMRD selected three priority investigation areas—Faleza Nord, Cazino Constanța and Eforie Sud—because of their potential suitability for seagrass development and their relevance to assessing sediment redistribution and anthropogenic pressure.

NEMOSENS micro-AUV missions in controlled areas of Constanța Port were technical trials, including Side Scan Sonar (SSS), onboard camera, and sensor configuration tests; they were ecological mapping/investigation campaigns using ROV video data recording at important points/AOI areas. Video acquired during these trials was severely constrained by turbidity and was unsuitable for reliable benthic classification. Complementary GoPro observations were

undertaken in coastal sectors, including Eforie Sud–Tuzla–Costinești, in collaboration with TUV Bulgaria, although unfavourable marine conditions limited systematic acquisition of new field data.

To continue developing the marine litter identification and delineation methodology, NIMRD used two underwater videos supplied by the Turkish project partner and analysed by the contracted specialist/POLARIKOS S.R.L. The files total approximately 104.6 minutes and 8 GB. Exploratory image enhancement and ML/AI detection and segmentation were tested; no associated SSS, navigation or CTD data were available for this analysis. Consequently, optical–acoustic fusion, georeferenced habitat delineation and quantitative habitat-health evaluation remain future tasks.

A major outcome is the clarification of a harmonised, traceable data workflow under the project Data Management Plan (DMP), from acquisition and metadata capture through QA/QC, annotation, processing and exchange between partners, within periodic online meetings. The proposed future SSS surveys will seek to discriminate sediment-dominated and hard-bottom areas and assess potential sediment coverage of the marine habitats in the Southern Romanian Littoral areas with sand-nourishment-built coastal protection arrangements. Confirmation of sediment thickness or historical habitat conversion will require independent reference data and/or repeated surveys in these impacted areas.

4.2. Introduction and objectives

EfxINNOs ("Establishing and Operating an Innovative Marine Technology Transfer Network for Enhancing the Transition to a Sustainable Blue Economy in the Black Sea Basin") is an Interreg NEXT Black Sea Basin cooperation project. Its underwater-monitoring component supports knowledge transfer and harmonised methods for seabed observation, benthic habitat investigation, and the identification of anthropogenic objects through AUV/ROV platforms, acoustic sensing, optical imaging, and exploratory ML/AI techniques.

4.2.1. NIMRD role and activity alignment

Activity	Romanian pilot contribution
A1.6 – Collect and harmonize data, images and videos from AUV and ROV	**mAUV operational tests; supplementary GoPro investigations; data inventory, metadata, quality checks and partner data exchange.**

4.2.2. Objectives and reporting boundaries for A1.6 Activity

The present report emphasizes the actual field-testing and supplementary optical-observation activities, done for description of works, under a reproducible methodology for underwater video and SSS acquisition, including the organization and QA/QC and processing. The exploration analysis undertaken on partners-supplied videos has some limitations in the interest/documentation regarding the relevance of sediment deposition, turbidity, and potential habitat shifts in other areas of investigation. But the technical cooperation and inter-partner data information flow was a completed activity, for preliminary observations, ongoing and future methodological observations on marine litter/marine pollution and habitat health.

4.3. Specific interest area and scientific rationale

4.3.1. Southern Romanian Black Sea coast

The southern Romanian coast comprises urbanised and tourist-oriented shorelines, coastal defence works, port infrastructure, and heterogeneous shallow-water seabeds, encompassing rocky or consolidated substrates, sandy sediments, and associated benthic assemblages that occur in different settings. Beach nourishment and ongoing coastal engineering works modify sediment distribution/saltation/coastal waters' turbidity, local seabed morphology and transparency/light conditions, with implications for benthic vegetation and other communities. These effects are site-specific and must be investigated rather than presumed uniform along the coast.

4.3.2. Selected priority investigation areas

NIMRD selected Faleza Nord, Cazino Constanța, and Eforie Sud as significant priority areas to be surveyed because their conditions are suitable for seagrass development, enabling several comparative investigations across locations/AOI selections and thus establishing whether seagrass is currently present or absent throughout these polygons. Their boundaries represent target investigation areas, not completed acoustic or optical coverage.

Area	Indicative polygon area	Selection rationale
Faleza Nord	**3,013,363 m² (301.34 ha)**	**Potential seagrass habitat; assessment of nearshore substrate and anthropogenic pressure.**
Cazino Constanța	**171,699 m² (17.17 ha)**	**Targeted investigation of seabed heterogeneity and potential benthic vegetation.**
4.4. Eforie Sud	**476,491 m² (47.65 ha)**	**Potential seagrass habitat and investigation of sediment redistribution in a modified coastal setting.**

The three mapped polygons total approximately 3.6616 km² (366.16 ha). Areas are read from the supplied map and should be verified against the project GIS polygon dataset before formal geospatial publication.



Figure 1. Selected Romanian coastal investigation polygons: Faleza Nord, Cazino Constanța and Eforie Sud (source: NIMRD-supplied working map).

4.5. Sediment coverage, turbidity and potential habitat modification

On the Romanian shore, the large-scale nourishment and sediment redistribution increased the suspended-particle concentrations, impaired underwater visibility and promoted burial of shallow benthic substrates. The project team identified concern over sediment coverage in the nearshore zone, particularly to approximately 5 m depth - this depth is a working focus reported by the team, not a mapped burial limit established by the present dataset. Also, optical observations may become difficult in such conditions, as demonstrated by the measurement and testing videos, collected with TUV.

A central consideration for future surveys is that the deposition of sand on formerly exposed hard substrata may progressively alter the character of the surface substrate and the associated benthic community, potentially favouring sediment-dominated conditions at the expense of hard-bottom assemblages. This transformation has already been demonstrated in part by the underwater observations and measurements within EfxINNOs A 1.6 Activities. The SSS data (backscatter and texture) may help distinguish exposed hard bottom, sandy areas, and mixed transition zones, subject to calibration and ground-truth validation. SSS alone cannot quantify sediment thickness or establish the prior habitat state, in comparison with historical mapping, repeat surveys and required sediment sampling

Conversely, some stable fine-sediment settings may be suitable for Zostera noltei, but the presence of sediment alone is not evidence of suitability. Light availability, sediment mobility/resuspention, hydrodynamic forcing and ecological conditions must also be considered. Restoration of seagrass is part of the broader regional environmental context and is not reported here as an EfxINNOs intervention.

4.5.1. Distinction between priority sites and operational test locations

Constanța Port basins were used for controlled operational testing of NEMOSENS AUV, not for completed habitat mapping of the three designated areas, approached in part for the first two areas in close collaboration with TUV; additional coastal underwater GoPro observations, including in the Constanta North, Eforie Sud sector, were supplementary with data completed by mAUV/SSS survey coverage.

4.6. AUV-based data acquisition methodology

4.6.1. 3.1 Platform and instrumentation

The Romanian pilot employed the RTSYS NEMOSENS micro-AUV for technical trials. The draft records configurations involving SSS, underwater GoPro-type imaging, CTD and DVL functions, including evaluation of a current-recording/ADCP-like operating mode. The exact mounted payload, firmware, acoustic frequencies, sonar range, altitude and operational settings were documented for each testing mission, and nominal capabilities were treated as measured performance - the draft lists 200 and 455 kHz as SSS frequencies, but these values require confirmation against mission logs and manufacturer documentation in the manufacturer's location.

4.6.2. Mission planning and safety

Survey designs were defined by site characteristics and objectives; navigation constraints; bathymetry and existing obstacles on the planned transects; and line spacing and overlap, operating depths, altitude above seabed, speed, acoustic range, and fixed camera orientation. Pre-deployment checks should include sensor mounting and balance, power, clock settings, storage, communications, weather and sea-state suitability, navigation readiness and recovery arrangements. The controlled port tests provided practical feedback on deployment, retrieval, configuration, and navigation behaviour, despite issues identified with SSS data recording that required the manufacturer's intervention.

4.6.3. Optical and acoustic acquisition

Optical acquisitions retained full-resolution originals, camera configuration, video start/end times, lighting and visibility observations. Where a target was visible and safe to approach, both contextual and closer views were recorded in the areas with low turbidity. Representative marine litter/impacted habitats scenes were useful for later classification. SSS acquisition preserved raw acoustic files, frequency, range, ping timing, gain settings, vehicle track, attitude, altitude and seabed-interaction notes, but georeferencing was an issue. Planned systematic surveys aimed for consistent along-track and across-track coverage and to avoid treating visually interpreted features, but the spatially validated scanning will require navigation linkage.

4.7. Operational tests in Constanța Port

Several NEMOSENS deployments were conducted in controlled port basins to test payload configurations and data-acquisition behaviour. The SSS files collected were test outputs used to assess the system, rather than a validated acoustic habitat dataset. Underwater videos were also acquired, but high turbidity and very low visibility prevented reliable interpretation of habitat. The draft records concerns about positioning and acoustic data distortion, which were communicated to RTSYS; the instrument was returned to France for technical intervention. The

report should not claim that those issues were fully resolved without subsequent evidence of service and acceptance testing.

4.7.1. Supplementary coastal GoPro observations

During periods when unfavourable marine hydro-meteorological conditions restricted new CTD and systematic underwater acquisition, NIMRD undertook targeted AUV operations together with TUV and ROV video reconnaissance in selected coastal pilot areas, especially North Constanta, Eforie Sud, and Tuzla–Costinești. Existing high-resolution recordings were examined for seabed characteristics and potential navigation obstacles -their spatial/depth interpretation depends on available location and depth metadata, including obstacle-depth mapping.

4.8. Field quality assurance and data limitations

A mission-level quality log of the record of missing sensor streams, unstable navigation, time offsets, poor camera visibility, incomplete acoustic coverage, corrupt files, and instrument faults was required within data QA/QC flagging, including technical equipment assessment, visual interpretation, annotation, acoustic interpretation, or georeferenced ecological mapping. The in-situ and port video material was retained as operational evidence but did not permit a reliable habitat classification.

5.4. Harmonised processing and analysis methodology

5.1. Data Management Procedures - aligned data flow

The project DMP is the control reference for partner data sharing and harmonisation. The present report describes the harmonisation principles documented in the supplied materials, rather than asserting compliance with the DMP encompassed. A project/common dataset package contains raw files, machine-readable inventory, provenance, collection settings, coordinate reference system, timestamps and sensor-clock information, QA/QC status, processing history, license/access conditions and responsible contact, and was built on GDrive, including processed and raw immutable data.

Stage	Minimum output	Control point
Acquisition	Original video, SSS, navigation and environmental files where available	Mission ID, equipment, operator, date/time, configuration
Inventory	File list, sizes, checksums, format information	Missing/corrupt file checks
Temporal/spatial alignment	Clock offsets, trajectories, depth/attitude, coordinate reference	Synchronization and navigation uncertainty
Preprocessing	Versioned images, sonar mosaics or candidate products	Preserve original, settings and software versions
Interpretation	Annotations, class definitions, expert review	Ground truth and uncertainty flags
Partner exchange	Documented transfer package and provenance	Agreed access, metadata and QA/QC conventions

5.2. Partners' video dataset analysed by POLARIKOS

Several datasets of ROV collected in Bosforous area were analyzed together with POLARIKOS in August 2026. Thus assessed two datasets MKV/H.264, Full HD underwater recordings, supplied through the Turkish project partner. They total 6,279.98 seconds (approximately 104.6 minutes) and approximately 8 GB. The recordings were mostly decodable, with localised damaged packets. The effective average frame rate was estimated at approximately 32.32 frames/s from decoded-frame timestamps; nominal container frame-rate fields were unreliable. Extraction and synchronisation should therefore rely on actual frame timestamps.

Dataset	Duration	Size	Key qualification
Video 1	4,195.84 s (69.9 min)	~5.3 GB	31 video packets without decoded frames; localised faults
Video 2	2,084.14 s (34.7 min)	~2.7 GB	One packet without decoded frame
Both	~104.6 min	~8 GB	No corresponding SSS, navigation, CTD or validated reference annotations supplied

5.3. Exploratory optical quality assessment and enhancement

The Turkish partner videos displayed blue–green colour dominance, red-channel attenuation, low contrast, haze and backscatter, varying illumination, crowded natural backgrounds and partly bio-colonised or occluded objects. The evaluated approaches included moderate CLAHE, colour compensation and dehazing, as well as underwater restoration approaches including PhISH-Net, U-shape Transformer, Semi-UIR and USUIR. Moderate CLAHE and colour correction offered useful visual improvements in examples; aggressive enhancement amplified noise or altered colours. A visually improved frame was assumed to improve object detection without comparison on annotated test data.

The recommended reproducible workflow was to decode and validate timestamps, to retain original frames, to mark corrupt/blurred/overexposed intervals, to generate versioned candidate enhancements, to review their effects visually and, when labels exist, using consistent downstream performance metrics; resizing was only with care because small objects associated with frail alga or marine litter may disappear.

5.4. Annotation and exploratory ML/AI

P3, together with an external expert/POLARIKOS, explored SAM 3, YOLO, and Grounding DINO, as well as models from the YOLO family trained on public marine-litter datasets. Results were unstable in low-contrast and cluttered scenes, and generic pretrained models did not support defensible project-level claims of detection accuracy, but may assist with human-reviewed pre-annotations. Candidate classes included containers, tyres, anthropogenic ropes/cables, other litter, vegetation, natural substrate, vehicle components to ignore, and uncertain objects. For continuous vegetation, an expert-validated semantic segmentation should be used where feasible, and several discrete objects/instance masks.

For a pilot, the recommendations focused on sampling (approximately 1–5 frames/s based on scene changes and underwater vehicle movement) and expert annotation (of 200–500 diverse frames, with second-reviewer checks and split by mission/video/location/time block rather than random adjacent frames). Future work will establish robust generalisation and precision, recall, mAP, or IoU.

5.5. Side Scan Sonar preprocessing: planned, not validated

The SSS workflow proposed in the project draft includes XTF inventory and decoding, navigation verification, bottom tracking, water-column/slant-range correction, intensity/gain normalisation, striping/noise reduction, georeferenced mosaicking, and expert interpretation. Appropriate processing takes into account sonar geometry, beam pattern, platform motion, and uncertainty due to the lack of validated optical–acoustic data fusion.

5.6. Multimodal integration and habitat delineation

At present, the co-acquired data becomes available, together with optical frames, sonar pings, positions, depths, attitudes and CTD records, and will be linked through a common time base and documented sensor offsets. Acoustic texture classes will be checked against optical imagery or field ground truth before being labelled as ecological habitats. Habitat polygons will increase confidence levels, provenance and interpretation criteria. Mapping of existing seagrass and screening of potentially suitable sedimentary settings are separate analytical outputs.

5.7. Habitat condition and human-impact framework

A future assessment may combine seagrass presence and spatial extent, visible vegetation cover and condition, substrate class, sediment cover, marine litter occurrence, turbidity/light constraints, and evidence of coastal engineering disturbance. Species identification and health metrics require ecological validation and consistent, repeatable sampling. The current datasets may support quantitative habitat-health scores, estimates of seagrass loss or verified habitat conversion.

5.8. Partner collaboration and knowledge transfer

5.8.1. Operational and technical cooperation

NIMRD exchanged technical observations with partners and with the manufacturer/RTSYS regarding NEMOSENS operation, navigation and SSS data quality, and the instrument was sent for service. This interaction supported refinement of acquisition procedures. NIMRD, together with an external expert/POLARIKOS (a technical service provider, not identified here as an EfxINNOs consortium partner), was deploying specific exploratory processing and recommendations.

5.8.2. Cross-border data exchange

Underwater recordings from Istanbul University enabled the continuation of exploratory processing, while locally acquired videos were unsuitable for benthic interpretation. NIMRD also discussed with IU, TUV and DUTH for the future sharing of ROV/AUV-derived video and imagery under common established formats (*.avi and *.mp4), metadata conventions and QA/QC principles for AUV and ROV files in parallel with physical and chemical data suport from fix platforms, such as Georgian buoy.

5.8.3. Joint activities and capacity building

The supplied reporting draft included records of participation in the 15–17 April 2026 partner meeting in Tbilisi, including technical coordination, stakeholder dialogue and knowledge transfer with students and early-career researchers. The project materials were improved and now mention a training-related review of AUV imagery from the Kavala session and cooperation

on marine observations and data-platform interoperability, including support for Georgian buoy-data work. These complementary actions demonstrated that harmonisation includes procedures, expertise and common decision-making, on the transferred/exchanged data sets/files.

5.8.4. Interoperability and dissemination

The reporting materials discussed preparation for EMODnet and prospective Copernicus Marine pathways, including metadata and quality requirements for marine observations. These activities were described as preparation, consultation or submission only when supported by actual submission receipts. An EfxINNOs DMP-aligned data package was facilitate FAIR reuse, but compliance with a specific pan-European standard depends on dataset type and destination platform.

6. Results, constraints and interpretation

Component	Evidence-based status	Interpretive limit
NEMOSENS SSS trials in Constanța Port	Technical acquisition, tests and measurements conducted	In process of validation of the seabed habitat map
Port underwater video	Recorded under very turbid conditions	Unsuitable for reliable benthic identification
Coastal GoPro reconnaissance	Targeted observations and examination of existing recordings	Not equivalent to full mAUV survey coverage
Turkish partner video	Videos processed exploratorily	No paired SSS, CTD, navigation or reference labels
Image enhancement and ML/AI	Candidate methods and preliminary examples tested	In process of model performance validation for habitat-health scores
DMP-oriented harmonisation	Workflow and partner coordination documented	Full cross-partner implementation
Sediment coverage/Marine litter / habitat transition	Priority scientific questions and planned SSS investigation	No agglomeration/thickness or before/after conversion

The most consequential lesson is that sensor integration, provenance, and field metadata will be designed at the time of acquisition. Neither post-processing nor advanced ML can recover missing spatial, temporal or ecological ground truth. High turbidity provides a strong rationale for complementary acoustic methods, but sonar products themselves require calibration and validation in future missions.

7. Next steps for Romanian areas of interest surveys

Confirm the post-service technical readiness of NEMOSENS AUV and ROV and record acceptance-test outcomes before systematic deployment.

Prepare site-specific survey plans for Faleza Nord, Cazino Constanța and Eforie Sud, including bathymetry, navigation hazards, transect spacing, SSS settings and realistic weather windows.

Acquire paired SSS, video, navigation, attitude, depth and, where feasible, CTD/light information with synchronised clocks and documented sensor offsets.

Preserve all raw acoustic and optical records; publish internal inventory, checksums, acquisition logs and processing provenance under the DMP.

Build expert-reviewed acoustic substrate classes (hard, sandy, mixed/uncertain) and verify against suitable imagery or ground-truth observations.

Compare sediment-cover patterns with historical bathymetric/habitat records or repeated surveys before inferring a transition from rocky to sandy habitat.

Agree an inter-partner ROV/AUV exchange package, metadata dictionary, class ontology, QA/QC flags and access rules; distinguish promised data from delivered files.

Create a diverse, locally annotated optical pilot dataset and evaluate enhancement/ML methods on an independent test set before making operational claims.

Develop habitat-condition indicators with benthic ecology specialists and clearly separate habitat presence, habitat suitability and habitat health.

8. Conclusions

The Romanian EfxINNOs pilots were advanced through operational mAUV testing and measuring, supplementary coastal video reconnaissance, exploratory analysis of partner-provided underwater recordings and development of harmonised data-management and processing methods. Although local port conditions and instrument issues prevented generation of a validated integrated habitat dataset, the work identified concrete technical requirements for future field surveys and demonstrated the practical value of inter-partner cooperation.

The next scientific priority is to apply systematic, quality-controlled SSS and optical acquisition in the three officially selected seagrass-potential areas and to share information with the project partners and relevant stakeholders. Thus, enabling a defensible characterisation of seabed substrate patterns and, where reference observations exist, investigation of sediment redistribution and potential changes in benthic habitat. Despite time limitations, quantitative ecological evaluations/conclusions will depend on adequate ground truth, time synchronisation and comparative evidence.

9. References and documentary basis

[1] NIMRD. Short Reports on the Work Performed (working draft supplied for revision).

[2] Technical Report 2 of external expert / POLARIKOS S.R.L., including pre-processing and exploratory analysis of AUV/ROV data and sonograms.

[4] NIMRD-supplied maps of Faleza Nord, Cazino Constanța and Eforie Sud priority polygons

[5] Technical clarifications supplied by the project coordinator during online project meetings

SECTION B – Data Harmonization

10. Harmonized Data Management for AUV Surveys

The AUV, equipped with both side-scan sonar and CTD sensors, enables high-resolution seafloor imaging and environmental monitoring. By carefully planning survey routes, optimizing sensor settings, and maintaining data integrity throughout the survey process, we ensure the quality of the collected data.

All data and metadata collected by the side scan sonar (SSS) and the CTD sensor will be stored and processed in accordance with international standards, ensuring interoperability. This approach enables seamless, standardized data processing using the most suitable software by adopting common file formats. This harmonization process standardizes data formats, metadata conventions, and terminology, enabling researchers to merge and analyze data from multiple sources effortlessly. It also enhances georeferencing accuracy and simplifies the integration of diverse data types, leading to more comprehensive and reliable scientific conclusions.

Raw survey data will be initially stored on a local computer and subsequently replicated to a cloud server, following a standardized naming convention. Once a survey is completed, the interpreted survey data will be stored as a Map Package in the shared cloud, ensuring that all relevant interpreted files, sonar mosaics, ground-truthing points, CTD profiles, and baseline files are preserved. The Map Package will be structured so that it can be easily shared with potential users, allowing them to open all necessary files and data intact.

10.1. Sonar data

Since all the AUVs have been delivered, we can now process the data collected during the preliminary mission. Initially, software such as SonarWiz was used to handle the hydrographic data. Given that we have only recently received the AUV, we are not yet able to fully replicate the cleaning and processing workflows currently performed in SonarWiz using open-source tools. As a longer-term goal, we plan to explore libraries such as pyxtf for Python (https://github.com/oysstu/pyxtf) to support more flexible, reproducible processing workflows once sufficient experience and validation have been gained with AUV-collected data.

The collected data are in XTF format, developed by Triton Imaging, Inc., which stands for eXtended Triton Format, an open format widely used for recording hydrographic survey data. An XTF file can be thought of as a “pool” of data. This means that during a survey, data can be added to the file at any time without needing to synchronize your data packets. Therefore, no storage space is wasted and no “holes” are created in the saved data stream.

For example:

- bathymetry data may be logged five times per second,
- Sonar data is being logged 10 times per second.

This work involves converting XTF data into the OGC GeoTIFF format, a standardized geospatial raster format that supports geographic metadata. The GeoTIFF format preserves the spatial reference and coordinate system of the data, allowing seamless integration with other geospatial datasets. By establishing these conversion and harmonization procedures at this stage, we aim to streamline the processing, analysis, and visualization of AUV-collected data, while maintaining compatibility with the overall data management framework and enabling

advanced analyses such as habitat mapping and machine learning applications.

To guarantee consistency and interoperability, EfxINNOs adopts the SeaDataNet (2017) guidelines as a foundation. Side-scan sonar (SSS) imagery is converted to OGC GeoTIFF, a widely accepted geospatial raster format across European marine data infrastructures, ensuring harmonized exchange, analysis, and integration of SSS data and full compatibility with platforms such as EMODnet, Copernicus Marine Service, and EDITO. The merged and converted XTF datasets from the planned surveys are shown in the figure below, visualized in QGIS in OGC GeoTIFF format using a custom color ramp, generated through code, that replicates the SonarWiz display for visual consistency.



Figure 16. Side Scan Sonar recorded data showing seafloor features captured during the planned surveys visualized using Quantum GIS software.

10.2. Environmental data from CTD

Environmental profile data from the CTD sensor will be structured according to the Ocean Data View (ODV) format. The ODV format organizes profile and time-series data into a fixed table structure with three column types, enabling standardized handling of measurements. Using ODV ensures that CTD data can be easily shared, integrated, and analyzed alongside other marine datasets in European infrastructures, maintaining interoperability with EMODnet, Copernicus Marine Service, and EDITO. The ODV format organizes profile and time-series data into a fixed table structure with three column types:

- **Metadata columns** (e.g., position, time, platform),
- **Primary variable columns** (value and quality flag),
- **Data columns** (e.g., measured environmental parameters).

Rows are categorized as comment rows, column headers, or data rows. This structure ensures compatibility with common marine science workflows and analytical tools, supports controlled vocabularies, and embeds sufficient metadata for full interpretability.

The EfxiNNOs data architecture will support the following SeaDataNet feature types for storage:

- **Point time series** (e.g., sea level or moored sensor data),
- **Trajectories** (e.g., underway data with continuous movement),
- **TrajectoryProfiles (varying x, y, z, t).**

For each type, row_groups will be organised based on the appropriate primary coordinate — time or depth, and follow the CF-compliant column naming conventions (e.g., Chronological Julian Date [days], time_ISO8601).

11.Harmonization of videos and images captured during the preliminary survey

To ensure consistency, comparability, and scientific validity in the documentation process, the capture of underwater video and photographic material has followed a standardized protocol. This includes using fixed camera settings such as resolution, frame rate, and white balance to maintain image quality across different dives and locations, as reported above. The GoPro camera was mounted under the AUV at a fixed angle relative to the seafloor to ensure consistent imagery across the survey area. Additionally, GPS coordinates and timestamps captured by the AUV were synchronized with the video recordings to allow for precise georeferencing.

Given that the AUV operates at an altitude of 5 meters and the surveyed waters contain high sediment concentrations, the resulting footage often appears hazy and color-shifted, making the visual identification of seagrass and marine litter particularly challenging. To address this, the method initially used was a LUT (Look-Up Table) cube file, developed and applied to correct the color balance of the footage, improving contrast and visibility of seabed features and thereby supporting more reliable identification and interpretation. However, a single, fixed color correction cannot compensate for effects that vary with the depth of the AUV along the dive and with the distance to the seabed within each frame. For this reason, the footage is now processed with the underwater video enhancement method described in Deliverable 1.7.

The enhancement method of Deliverable 1.7 is based on the physics of light underwater. Water absorbs red light within the first few meters, while suspended particles scatter light back into the lens as a haze (backscatter) that reduces contrast and gives the footage a blue-green appearance. Since the AUV keeps a constant altitude above the seabed, its depth follows the bathymetry, so the color balance changes considerably within a single video.

To address this, sixteen enhancement methods (physically based methods, pretrained deep learning networks and classical dehazing methods) were implemented and compared on the project footage. The Natural method, developed within the project, gave the most natural colors of all methods tested, rendering the seagrass olive green and the sand light beige, while keeping the colors as stable from frame to frame as in the original footage and more than doubling the contrast.

The method estimates the haze and the attenuation of the water from each video, using the range to the seabed derived either from the Depth Anything V2 network or from the AUV altitude in the telemetry log, and inverts the image formation model to recover the true colors of the scene. It also reduces the correction in open water and at altitudes above 6 meters, so that frames showing mostly water are not given artificial colors. Additional options, such as a particle filter that removes the streaks produced by suspended particles, multi-frame denoising

and local contrast enhancement, further improve the clarity of the footage. The enhanced video is saved together with a matching copy of the telemetry log, so that it can be used directly for seagrass detection and georeferencing.

These standardized practices, together with the color correction workflow, improve the reliability of species identification and habitat condition assessment, while also facilitating future data integration and long-term monitoring efforts by enabling repeatable methodologies and accurate comparisons over time.

A close-up screenshot showing the color correction applied via the LUT file to GoPro imagery is shown in Figure 17 below, while Figure 18 presents a before-and-after comparison of the LUT correction applied to the AUV video footage.



***Figure 17**. Cleaned underwater image captured during the field expedition using a GoPro camera, showing healthy stands of Posidonia oceanica and Cymodocea nodosa meadows. The video confirmed species presence and seagrass condition in situ.*

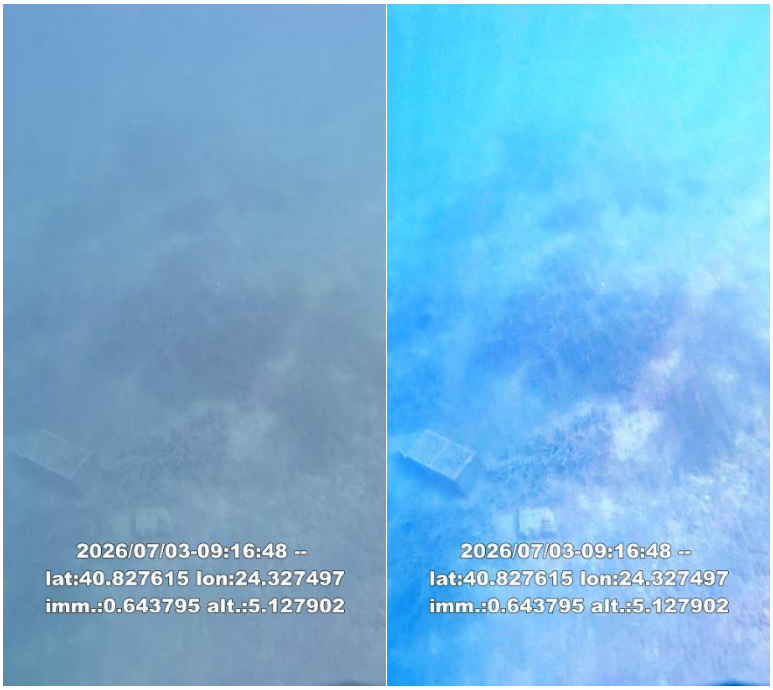


***Figure 18**. Before-and-after comparison of LUT-based color correction applied to AUV video footage, showing improved visibility of seabed features under sediment-affected water conditions.*